Forward angle proton energy spectra in the ^{64}Zn + ^{112}Sn reaction at 47 MeV/u

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Forward proton spectra acquired with NIMROD [1] in the first campaign in 2001 using 47 MeV/u ^{64}Zn projectiles exhibit intriguing high energy tails up to 200 MeV. In order to confirm that these are, indeed, high energy protons and not an artifact of non-physics effects, ie double hits where two protons enter the CsI at the same time and are identified as a proton with the apparent energy being the sum of the two protons, we decided to mount a simple experiment that discriminates against double hits and can confirm or refute these interesting high energy protons.

47 MeV/u ^{64}Zn ions were accelerated using the K500 Cyclotron at the Cyclotron Institute at Texas A & M University. The Zn ions were incident on a ^{112}Sn target. A single Ring 2-3 module from NIMROD was placed in a chamber at the same distance from the target as it is in NIMROD. To discriminate against double hits, we installed a 6mm thick CsI detector with the phototube detecting the CsI light from the side rather than the back like the NIMROD CsIs. In this way we can in principle obtain particle identification from each of the CsI detectors using pulse shape analysis as well as using the signals from each to obtain particle identification information from the ΔE vs E map.

Fig. 1 shows the particle identification map of the hydrogen isotopes. The horizontal axis shows the CsI fast signal from the front ΔE detector and the vertical axis shows the CsI fast signal from the back detector. Excellent separation between protons, deuterons and tritons are observed. This technique allows to discriminate against double hit protons as the ΔE signal will be on a different line from the proton line if two protons enter the front CsI in the same event.

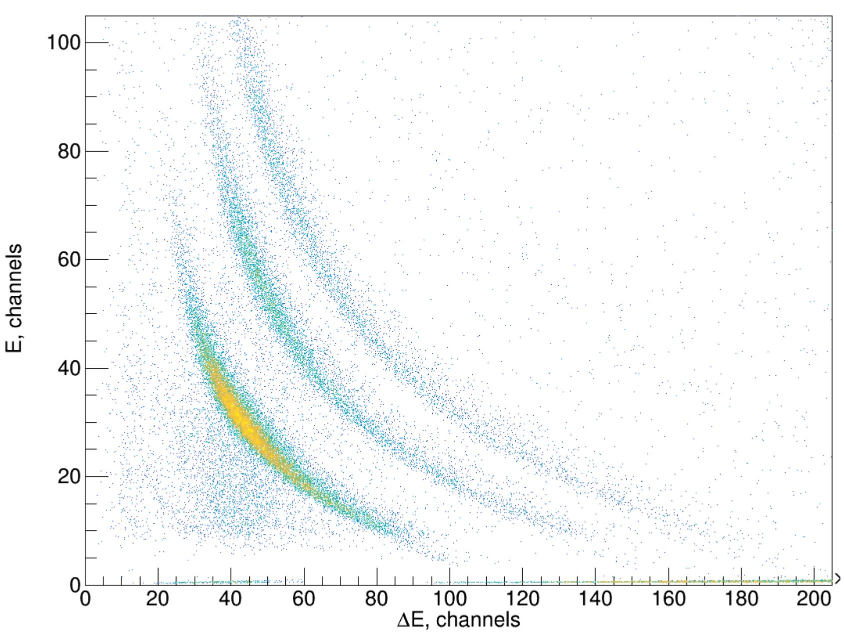

FIG. 1. E vs ΔE distribution of hydrogen isotopes.

Fig. 2 shows the slow vs fast map of the ΔE CsI detector. Excellent proton, deuteron and triton separation is achieved as well. The leftmost line includes cosmic muons that travel through the detector, gamma rays and neutrons as well as, importantly, protons that have passed through the ΔE into the E detector.

The particles were linearized using the now standard NIMROD linearization software [1]. Linearizations were performed on the particle identification map shown in figure 1 as well as the slow vs fast of the front ΔE CsI. The system was calibrated by using a 55 MeV H2 beam from the K500. Several peaks were observed that were used as calibration points. The primary peak was from beam that passed through the target. There was another peak that corresponded to beam that passed through the target frame. Finally there were events where two protons from the beam passed through the target in a double hit scenario and they appeared to the right of the deuteron line in the CsI dE vs E particle identification map demonstrating the discrimination against double hits that this setup provided.

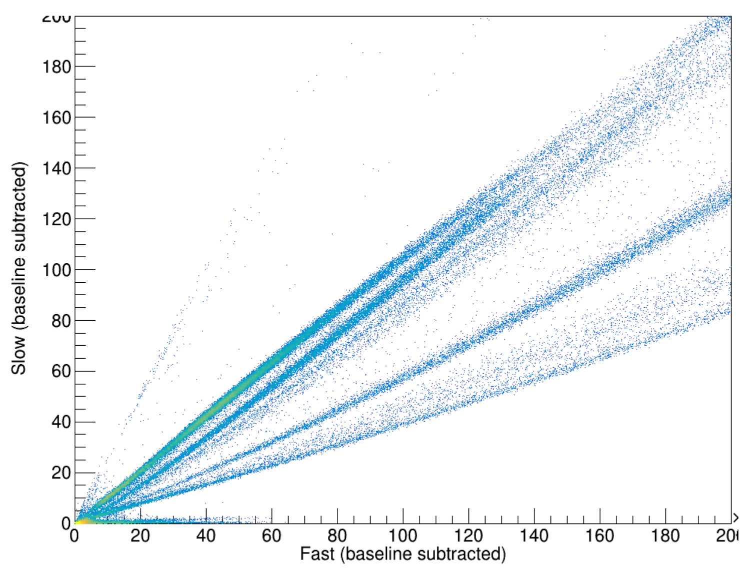

FIG. 2. CsI ΔE Slow vs Fast.

The histogram in Fig. 3 shows the calibrated protons spectrum that was obtained from this experiment. The high threshold is seen because only identified protons that entered the E detector are shown. Since we used only one module of NIMROD, this spectrum is a minimum bias spectrum. The earlier experiment [2] did not have a minimum bias trigger whose spectra are currently accessible. Data from this experiment were separated into bins of centrality with bin 1 being the most peripheral and bin 4 being the most central (violent). We chose proton spectra from bin 2 as having the most representative spectra relating to min bias. The closed circles represent the differential multiplicity proton data from bin 2. The present experiment was normalized at the peak to make the comparison. We observe good agreement in the peak and high energy tail of the experiment indicating that the high energy tails observed in that and other similar experiments do not result from double hit protons.

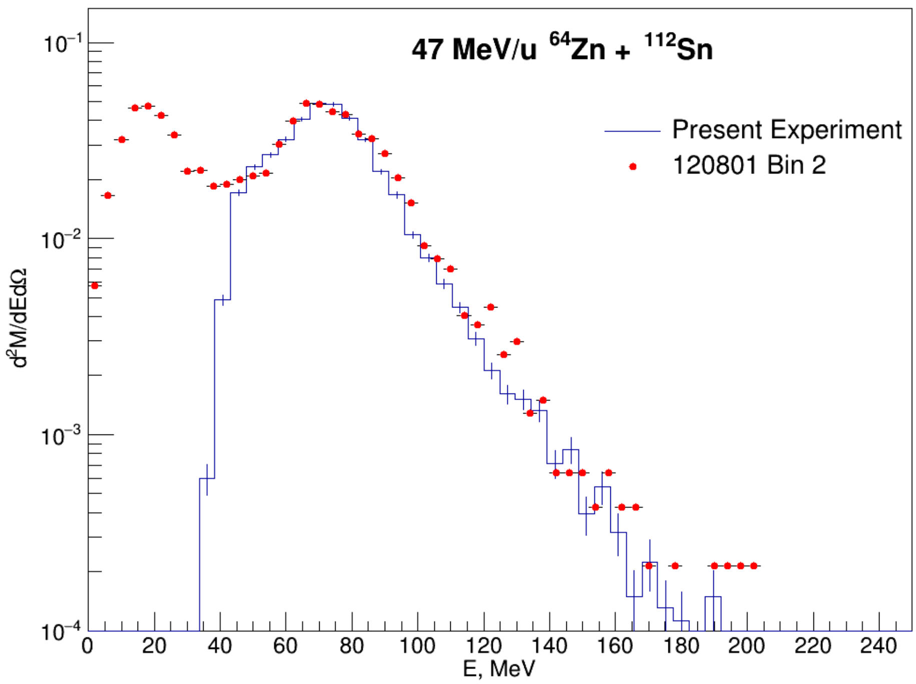

FIG. 3. Blue histogram: NIMROD Ring 2 proton spectrum from the present experiment. Only protons that entered into the E detector are shown resulting in the high threshold due to the 6mm CsI ΔE detector. Red closed circles: NIMROD Ring 2 proton spectrum from the previous experiment [2].

[1] S. Wuenschel *et al*., Nucl. Instrum. Methods Phys. Res. **A604,** 578 (2009).

[2] L. Quin *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2003-2004), p. II-31.